LOAD MONITORING FOR OPERATORS' LOAD MANAGEMENT

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Keywords: ATCOs, ATCO load model, load monitoring, load management

Abstract

The proposed lecture deals with the operators (namely aircraft pilot and air traffic controllers) load monitoring for developing the load management. By developing and introducing the highly automated systems, the role of pilots and ATCOs are shifting from the active controlling to the passive monitoring or as it can be said to supervising the aircraft and air traffic. Therefore, the operator models and their load monitoring, load management becomes to the level of the most important tasks. This lecture introduces a new operator model in which the situation awareness is supported by highly automated systems and the emergency situation should be managed by the pilots and controllers. There will be defined the information, task, work and mental loads, and their possible monitoring. The developed load monitoring systems will be discussed. The introduced concept is validated by use of flight simulators (one middle size passenger aircraft and one small aircraft flight simulators). The results tests and measurements will be represented and discussed. Finally, the load management concept will be developed.

1 Intorduction

Advances in information, computer, navigation and communication technologies catalyze the development of highly automated systems, as future air traffic management (ATM) systems. A large number of aerospace companies, universities, institutes are working on future autonomous systems and worldwide, several mega international and national projects have been initiated for the research, development and implementation of systems, regulations and procedures for future air traffic management such as; the Single European Sky ATM Research [1] in Europe, US the Next Generation Air Transportation System [3] in the United States, the Collaborative Actions for Renovation of Air Traffic System [4] in Japan, and the SIRIUS (Impulsionando o Desenvolvimento do ATM Nacional [2] in Brazil etc. These investigations have been introduced countless technological and system innovations in operators' working environments. In these systems, the role of operator (pilots, ATCOs) is changed from active control to passive monitoring by introducing the intensive automation. In case of active control, the operator deals with continuously situation awareness, decision-making and control actions; while, in case of future automated systems, the operator monitors the operating system and only in an abnormal and/or an emergency situation should initiate active control. The work quality of passive operators depends on their loads, namely information, task, work and mental loads. Especially, the information and mental load as physical - psycho-physiological condition play the much greater role in future systems.

The proposed lecture deals with the developed concept of load measuring and management systems, including (i) integrating sensors into the operators' working environment which can be placed into the side-sticks and applied computer mouse, (ii) operators' heart rate measurement with various flight scenarios such as visual meteorological condition (VMC), instrumental meteorological condition (IMC) and system failures (iii) utilization of eye-tracking glasses (iv) measurement of electrodermal activity (EDA), (v) outside measuring equipment. Due to the consequent effects of these developments, (i) reducing operator loads on the subject, (ii) increasing situational awareness, (iii) managing the operators' actions, (iv) increasing the quality of decision, (v) increasing safety in critical moments. The developed elements had been deployed already in the flight simulator and ATCOs working environment. The major concepts, designs and developed equipment and some measured data will be outlined.

2 Future advanced automation in operators' working environment

While technology has helped drive improvements in the aviation industry, automation has also increased significantly. For example, pilots in loop receive company information via datalink and routinely use the autopilot to fly the aircraft. Automation is used to provide information (i) to the pilot, controlling the aircraft and managing aircraft configurations and (ii) to the ATCO, monitoring, detecting and decision support systems, namely surveillance, conflict detection, conflict resolution.

The concept of different levels of automation (LOAs) has been pervasive in the automation literature since its introduction by Sheridan [5]. According to Sheridan [5], there are 8 different Level of Automation (LOA), corresponding to different uses and interactions with technology, enabling the operator to choose the optimum level to be implemented based on the operational context, from the Level 1 (operator's fully manual control) to the Level 8 (fully automated control). These levels are [6]:

1. The computer offers no assistance; the human operator must perform all the tasks;
2. The computer suggests alternative ways of performing the task;
3. The computer selects one way to perform the task and
4. Executes that suggestion if the human operator approves, or
5. Allows the human operator a limited time to veto before automatic execution, or
6. Executes the suggestion automatically then necessarily informs the human operator, or
7. Executes the suggestion automatically then informs the human operator only if asked.
8. The computer selects the method, executes the task and ignores the human operator.

In most cases, an automated system operates perfectly well without a human operator being actively involved and empowers human operators to be more efficient and productive in their tasks. However, there are circumstances when automation does not function as intended, when an emerging situation necessitates a manual change to the automation parameters or if anything goes wrong. On the other hand, automation will not solve all the aviation industry's problems. Even with the automation improvement in aviation, some new concerns regarding an acknowledged problem may arise from different ways of operating. For example, operators' (pilots and ATCOs) actions; including situation awareness, decision making, information analysing become to level of most important issues with the advanced automation systems, thus may generate extra problems on operators such as the automation surprise [6] changes in operators' vital health signs: heart rate, skin conductivity, blood pressure, skin temperature and so on [7,23].

The future operator supporting systems will contain;

- sophisticated info-communication systems,
- monitoring the operator loads and,
- supporting the situation awareness and decision making
- managing the operator total loads

Developed monitoring systems were integrated into the operators' working environment which is aimed at monitoring and managing the operators' total load systems, namely work, task, information and mental load.

3 ATCOs model applicable on pilots

With increasing traffic complexity and stress on conflict detection and resolution, the available time for situation awareness and decision making might play the most important role in the success of the performed actions. Secondly, automation initiates a change in operators' role. The role of pilots is changing from flying the aircraft to managing and supervising its systems and ATCOs will monitor the processes instead of direct and active control. This makes their job more monotone, while in case of an abnormal or an emergency situation. Operators might solve problems based on their knowledge-based behaviour. Therefore, human aspects and mental condition will have an even higher role in the future ATM, compared to the present circumstances. Therefore, the operators' model was redefined (Fig. 1.).

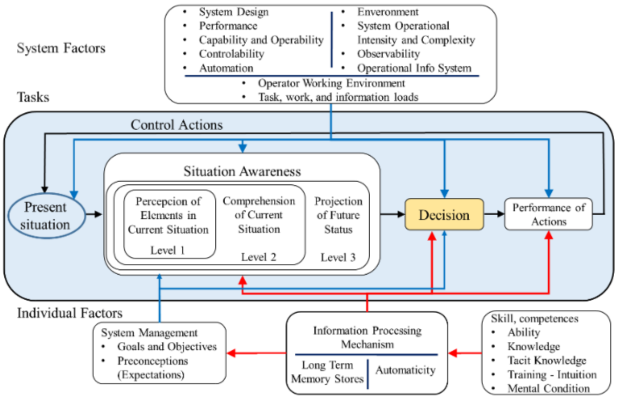

Fig. 1. Situation awareness model

The ATCOs model, which can be applied to pilots after minor changes, can be defined by two different approaches. On one hand, the situation awareness and decision making is the central element of the model. Fig.1. shows the model [8,9] developed by adaptation of the well-known and probably the most used model created by Endsley [10,11]. The situation awareness is made at three different levels:

- Level 1 - encompass and awareness of specific key elements of a situation
- Level 2 - comprehension of a current situation, integration of that information in the light of operational goals,
- Level 3 – an ability to project future states of the systems.

In this model, the situation is evaluated from the present situation instead of the state of the environment as defined by Endsley. The model is improved by including the actual (present) mental condition of operators into the individual factors because in the highly automated systems the role of the psycho-physiological condition of the operators is increasing.

As it is investigated and well known, the success of situation awareness and decision making depends on human behaviour (skill and performance) and operators' loads. As Rasmussen [12] thirty years ago defined, the situation awareness and decision making might be realized on three different levels. The first level, the so-called skill-based control is applied by the operators when the situation is normal and the operator can easily recognize the situations and can work 'automatically'. At the second level, the operators must recognize and identify the situation and apply the rule-based solutions to reach the expected situations. In case of abnormal flight situations, the operators must derive the solution with their knowledge and practice. This is the knowledge-based level.

The second approach applying to the description of the model is based on the operator loads. The created model (Fig.2.) contains the task, information, work and mental loads. The task load is generated by the number and hardness of tasks to be solved. It depends on airspace demands, interface demands, traffic regulation, airspace design, traffic planning and weather condition etc. In the case of highly automated systems, the changes in traffic intensity, abnormal and an emergency situation may generate several extra tasks.

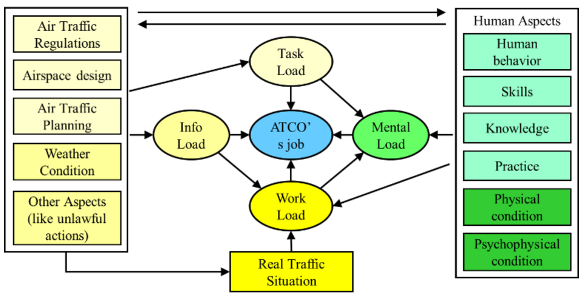

Fig. 2. ATCO's work model

The task load is generated by the number and hardness of tasks to be solved. It depends on whether condition, infrastructure condition, traffic regulation and planning, and traffic complexity. The information load is applied for characterizing a relatively new problem, initiated by supporting the operators with too many and partly not harmonized information from the different sources. For example, weather forecast information and weather condition reported by pilots in the same sector. The task and information loads together with real traffic complete the workload of the operators. And workload depends on real traffic conditions, traffic complexity, real condition of infrastructure, the real weather situations, etc.

Finally, the actual physical and psycho-physiological condition together are called as mental load. This load depends on human behaviours, skills, knowledge, practice, too. The mental load plays a determining role on the so-called subjective situation awareness and decision making of operators.

The developing operator load management system requires to use new methods and a wide range of micro sensors integrated into the operators' working environment.

4 Development of The ATCOs' Working Environment

4.1 Eye Tacking Systems

Over a hundred years, eye tracking technology has undergone rapid development and growth that has increased its popularity amongst practitioners and researchers from a wide variety of disciplines [13,14,15,16]. Eye movements reflect human's true emotions and cannot be hidden unlike other emotional demonstrations such as hand movements, mouth changes or voice changes [30]. Thus, by observing and studying the eye movements it's possible to determine the real preferences of an operator related to an area of interest during the experiments. The technology of Eye-tracking has used in many scientific studies such as in reading [17,18] human- computer interaction [19,20] in the investigation of the pilots' actions [21]. In aeronautics, the first eye tracking measurements were realized in flight and ATC simulations. Optical measurements were used, namely, video recorded by cameras mounted into the working environment in the front of the operators, and /or on the headband. The head positions were measured by wearing special items by operators. In this research, Tobii Eye-tracker has been used to record the visual patterns of the pilots through failure scenarios, such as engine failure and equipment failure. Fig.3. shows the pilot' eye movement during the engine failure. Several areas of interest in the cockpit were defined to study gaze allocation during the simulated scenario by authors.

Fig. 3. Tobii eye-tracker gaze plot: Fixational eye movements of pilot during the engine failure scenario

Fig. 4. Tobii eye-tracker heat map: Visualisation of where pilot looked during the engine failure scenario

According to the result in Fig.3, after the engine failure, the pilot spent most of his time gazing at the engine instruments and finding the best place to make a precautionary landing somewhere off of the airport.

4.2 Use of Integrated Microsensors

To measure the selected physiological parameters, to identify changes in operators' workload and in a mental state, a side-stick and a computer mouse with integrated sensors were developed (Fig.5.). These integrated devices consist of a heartbeat sensor, skin conductance sensor, temperature sensor, and strain gauges to measure grasp force applied by pilots on the handle.

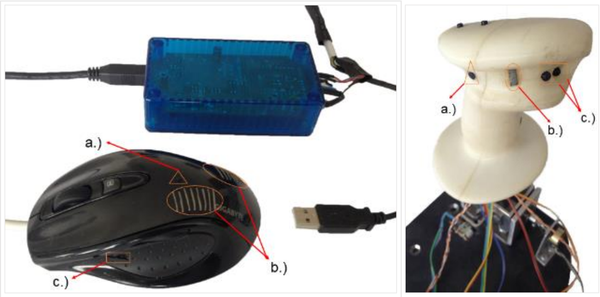

Fig. 5. Integrated microsensors into a computer mouse and a side-stick (a.) skin resistance, b.) skin temperature sensors c.) heart rate sensor

The aim of this investigation is to collect all the critical information by sensing the operators' healthy signs and storing in a computer by connection of USB connector. This method has been used in the ATC/ATM simulation laboratory at Budapest University of Technology and Economics (BME). Similarly, these microsensors are actively used in hospitals to measure heart rate and oxygen level of patient blood.

4.3 Heart Rate Measurement

According to the National Emergency Medical Association, a normal value of heart rate is between 60 to 90 beats per minute. However, heart rate depends on the individual, age, heart condition, body position (whether the person is sitting or moving), body size, emotions (under stress situation, surprise, happiness, anger, fear, sadness, and anxiety) and skin temperature. Worldwide scientific research has shown that when a person experiences a stressful event, it brings on a number of physiological changes, such as (i) increase in heart rate, blood pressure and blood glucose, (ii) starts to breathe more rapidly, (iii) increasing alertness (hearing may become more sensitive), (iv) may begin to sweat.

In this study, the heart rate of the pilots was recorded through the scenarios with heart rate sensors by a flight simulator is examined. The purpose of the study reported in this paper was to show how pilots' heart rate is affected by various flight factors through simulated scenarios. This would provide a better understanding of the relationship between operators' loads and task complexity. In this measurement, three scenarios were created: (i) Visual Meteorological Conditions (VMC), (ii) Instrument Meteorological Conditions (IMC), (iii) IMC with ADI (Attitude Directional Indicator) failure.

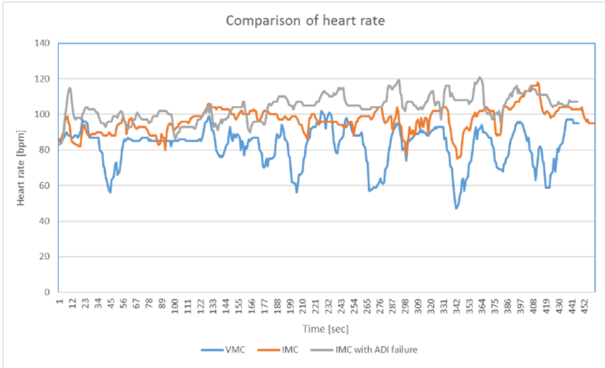

Fig. 6. Comparison of heart rate under the created scenarios

In the first scenario, all pilots performed a visual approach procedure in a full flight simulator while their heartbeats were recorded with a heart rate monitor (Fig.6). This task requires significantly less pilot effort which induces less workload. Because pilots have strong visual references with the horizon which means they are able to see in front of and around their aircraft while in the air, (Heart rate average: 82,4 bpm- Standard deviation:10,8- RMS: 83,1). The second scenario was created the significantly higher workload and accordingly stress, resulting in the increase in pilots' heart rates, (Heart rate average:96,8 bpm- Standard deviation: 6,95- RMS: 97,0). The third scenario is the most stressful operations a pilot can carry out. In simulator sessions, pilots being monitored showed the largest heart rate increase (Fig.6).

As it can be seen in Fig.7. that in case of the first scenario, the average of the heart rate (82,4 bmp) and the amplitude have the smallest value where the standard deviation (sd:10,8) has the highest value compared to the second and third scenarios.

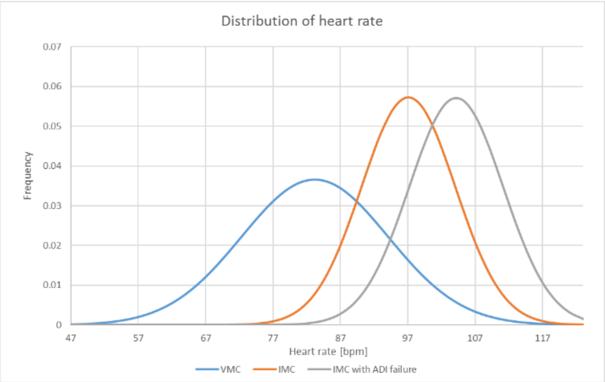

Fig. 7. Distribution of heart rate under the created scenarios

It can be also found that If the complexity of the task is increasing, the average of the heart rate is also significantly increasing.

4.4 Electrodermal Activity Device (EDA)

The measurement of electrodermal activity (EDA) has a long tradition starting in the 1800's and it has been used in a wide variety of studies related to psychology. EDA is an efficient indicator of arousal reflecting the activity of the sympathetic branch of the autonomic nervous system [24]. Different characteristics of electrodermal activity are important psychophysiological indicators of the emotional state, studied extensively in adults [26] as well as infants [25].

For the purpose of the present study, skin conductance activity of an experienced pilot was measured on a flight simulator. Open source bio-monitor for electrodermal activity (Obimon), a new low-cost, small and reliable device capable of synchronized measurement was used to record EDA from the wrists and shoulders of the participant (Fig. 8.)

Skin conductance is caused by the activity of sweat glands. And sweating causes a brief drop in the electrical resistance of the skin. This resistance also can be measured by means of electrodes placed on the operators' wrist and shoulder.

Fig. 8. Electrodermal activity device (EDA) usage in the flight simulator

5 Operators' Load Monitoring and Managing Rules

As it was discussed earlier, there are four types of operator loads i.e. work, task, information, and mental load.

Two different type of load management methods can be used; (i) assign a scoring method - say in [0,1] to all the measurements and (ii) mathematical modelling.

According to the assign a scoring method, all the measurements should be transferred to scores on a 0 – 1 for each operator load (Fig. 9.) where each element should have a weighting coefficient corresponding to different environmental conditions, abnormal situations and. failures. Each situation can generate a weighting coefficient between 0 to 1 and if there is more than one situation which play a role at the same time, the total score will be the sum of all weighting coefficients.

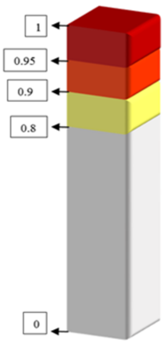

Fig. 9. Demonstration of the load model on a 0 - 1 scale

According to the developed model in Fig.9. the score is 0 if there is a very normal task of load measurement and it is 1 when an operator's load may cause a serious accident.

According to the mathematical model, two different rules might be used: (i) If one of the operator's load reaches the threshold, where is the score,

- 0.8 warming signal must be generated,
- 0.9 calling the special attention on continuously monitoring the operating condition,
- 0,95 actions are required

(ii) combination of at least two loads, namely in a case when any two type of load coefficients, reach to 0.7 or above:

- 0.7 - warning
- 0.8 monitoring and
- 0.9 – action required.

The metrics [27] and transformation of the measurements to the scores, as well as the definition of the warning levels, need further studies and might be defined depending on the operational condition and environment. The management can be developed by use of more sophisticated methods, like Markov decision support.

The control field of the cockpit can be designed with projecting the most necessary information (including loads, tasks, advice) in real-time mode to the cockpit window instead of having a series of wide screens in control panels. (Fig. 10.). It will help operators to manage their total loads more efficiently and reduce their stress levels at the same time.

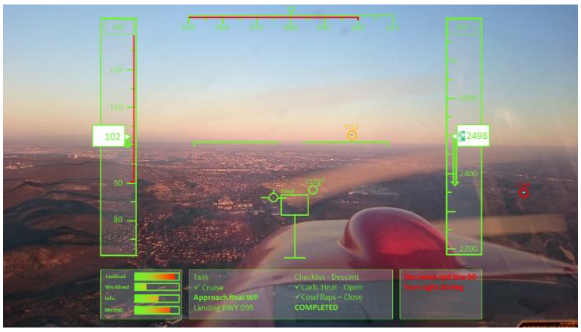

Fig. 10. Fig. 10. Future load management design in cockpit

As it can be seen in Fig. 10 (left-bottom) that there is four type of operator loads which are showed by small colourful columns, vary depending on the measured loads. So each column basically shows the level of the pilots loads. The second part is the task zone (Fig. 10. middle-bottom) which is associated with the air-ground communication and recommendations from pilots and air traffic controllers to improve communication. And finally, the third part is the advice part which can be seen in Fig. 10. (right-bottom). Pilots receive all the necessary advice on the cockpit window from the ground (ATCOs, aircraft remote control centres, robot pilots on the ground) or from the board (robot pilots or other aircrafts' pilots). For example, with upcoming technologies, the traditional two pilot set-up will be reduced to one on board and one robot co-pilot on board or on the ground. The advice which will come from these virtual robot pilots can be also shown on the cockpit window.

6 Conclusion

Because of the rapid technological changes, the role of pilots and ATCOs are in a transition from active controlling to passive monitoring. In this changing environment, the traditional operator model has to be redefined hence the concept of the future operator model was developed and introduced in this paper. Management of mental and information loads are going to have a greater role in the new working environment, which requires more advanced supporting system. Because, the subject, as operator generates his decision on the basis of his subjective situation analysis depending on the available information and his psycho-physiological condition. Therefore, operator' loads, includes the task, information, work and mental loads. are needed to be measured and managed.

Furthermore, this paper discussed a method how operators' total load can be measured, monitored and managed. This research gave insight into the application of developed side-stick and computer mouse with integrated sensors and also the usage of following devices in the operators' environments: Tobii eye-tracker, heart rate monitor and electrodermal activity device. There were shortly described some preliminary results of study which are validated by use of flight simulators (one middle size passenger aircraft and one small aircraft flight simulators) at the Department of Aeronautics, Naval Architecture and Railway Vehicles, at the Budapest University of Technology and Economics.

By analysing the preliminary test results, the applied methodology showed that the developed system can be applied in the pilot training, ATCOs' working environment [29] car drivers' environment [28], etc.

Due to the consequent effects of these developments, (i) reducing operator total loads on the subject, (ii) supervising and managing operators' actions, and (iii) increasing situational awareness, quality of decision, and safety in an abnormal or an emergency situation.

This project was initiated as a long-term research program and was supported by HungaroControl - Hungarian Air Navigation Services.

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